# Wide Bandgap Semiconductor Devices and Systems for Communications in Extreme Environment


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***Abstract*—The feasibility of gallium nitride based wide bandgap semiconductor devices for signal amplification in extreme planetary environment is investigated. The measured performance of these devices at S-band, X-band, and Ka-band are presented. The data indicates excellent performance at the above frequencies. Potential application of these devices includes communication systems required to operate in the extreme hot environment of Venus and in the extreme cold and high radiation environment of Jupiter's icy moons.**


## I. Introduction

NASA's mission requirements and operating environments are diverse and completely different for each mission. This is especially true in the case of NASA's discovery and new frontier science missions (e.g., to Venus and Jupiter) and exploration missions (e.g., Artemis to Moon and Mars). Hence, it is important to be cognizant of these diverse requirements while planning a mission. Additionally, while operating in the harsh environment of space, the devices and systems for communications and data handling are subject to extreme temperature variations and high energy radiation. Furthermore, they are required to have small size and low mass, consume small amount of DC power, operate with high efficiency, and perform reliably over extended periods. Wide bandgap semiconductor materials such as gallium nitride (GaN) and silicon carbide (SiC) have large bandgap, high electron saturation velocity, excellent thermal properties, and good chemical stability. Consequently, high electron mobility transistors (HEMTs) fabricated on epitaxially grown GaN-on-SiC wafers can operate at higher frequencies, deliver high RF output power with good linearity, high power added efficiency, and operate at elevated temperatures [1]-[4]. Therefore, GaN HEMTs are suitable for the above types of missions.

This paper builds on our previous development efforts on GaN based reconfigurable fully solid-state microwave power modules for S-band and X-band communications applications [5]-[7]. In this paper, we extend the above effort to the Ka-band frequencies and report on the architecture and the characterization of a high-power amplifier module.

## II. State-of-the-Art of GaN High Power Amplifier Modules

Based on our literature survey, we have compiled the state-of-the-art (SOA) data on the output power and power added efficiency (PAE) of GaN MMIC high-power amplifiers (HPAs). These HPAs have been assembled for the purpose of RF performance evaluation, as a standalone module without an integrated DC electronic power conditioner (EPC) or power supply. The output power levels as a function of the frequency for these HPA modules are presented in Fig. 1 (a). In addition, the figure presents the intended applications of these modules. The corresponding module PAE is presented in Fig. 1(b).

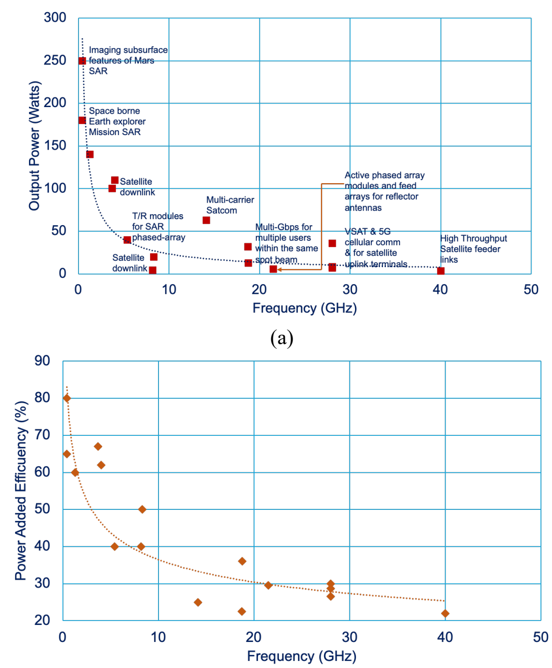



Fig. 1. GaN MMIC HPA module performance as a function frequency. (a) Output power and intended applications. (b) Corresponding power added efficiency.

## III. State-of-the-Art of GaN Solid-State Power Amplifiers

In this section based on our literature search, we present the SOA data on the output power of GaN MMIC solid-state power amplifiers (SSPAs) that are currently flying in space. The major difference between the HPA presented in the previous section and SSPA is that the SSPAs have an integral EPC, and the combined unit is space qualified. The SSPA

output CW power levels as a function of frequency and corresponding space applications, are presented in Fig. 2.

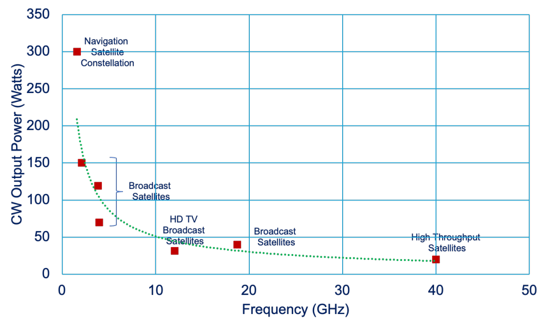



Fig.2. GaN MMIC based 7space SSPA CW output power vs. frequency.

## IV. Ka-band High Power Amplifier Module

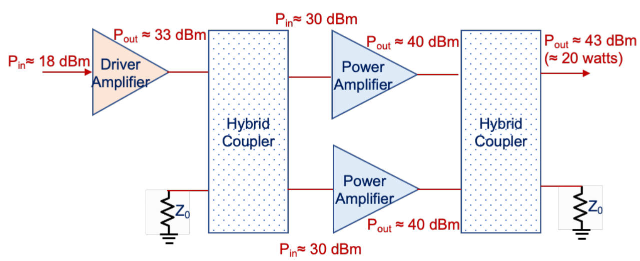



Fig.3. GaN MMIC based Ka-band HPA module architecture.

### A. GaN Ka-band HPA Module Architecture

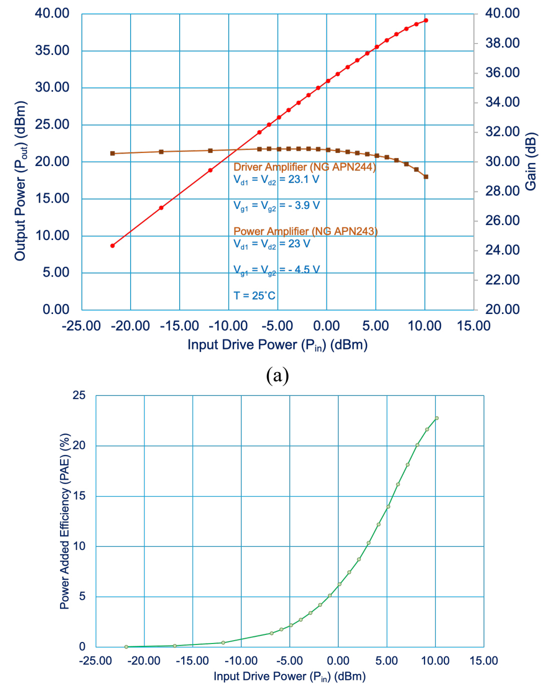
The architecture of the GaN Ka-band HPA is presented in Fig. 3. The module consists of a driver amplifier driving two power amplifiers arranged in a balanced configuration. The theory and advantages of using a balanced amplifier configuration are explained in [8]. The input/output power levels indicated in Fig. 3 are ideal values and do not consider the losses associated with the 3-dB hybrid couplers. The target output power and PAE of the HPA module is 20 watts CW and 23%, respectively, over the 25 to 28 GHz operating frequency range.

### B. GaN Ka-band HPA Module Measured Characteristics

For the initial demonstration, a driver amplifier and a single power amplifier were cascaded to form the HPM module, and the overall output power, gain, and PAE of the HPA module was measured across the 25 to 28 GHz frequency range. As an example, the measured output power and gain as a function of the input drive power at a fixed frequency of 25.0 GHz is presented in Fig. 4 (a). The output power is close to 10 watts. The corresponding PAE is presented in Fig. 4 (b).

## V. Conclusions and Discussions

The SOA RF performance parameters for GaN based HPA modules and SSPAs are presented. The architecture for a 20-watt Ka-band HPA module is presented. As an example, the measured output power, gain, and PAE at 25 GHz for a driver and a power amplifier cascaded is presented. By integrating a second power amplifier in a balanced configuration as shown in Fig. 3 it is possible to achieve the desired output power of 20 watts.




(a)

(b)

Fig. 4. GaN MMIC HPA module measured performance characteristics as a function of the input drive power at 25 GHz. (a) Overall output power and gain. (b) Corresponding power added efficiency.

## References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